The Nature of Particle Physics

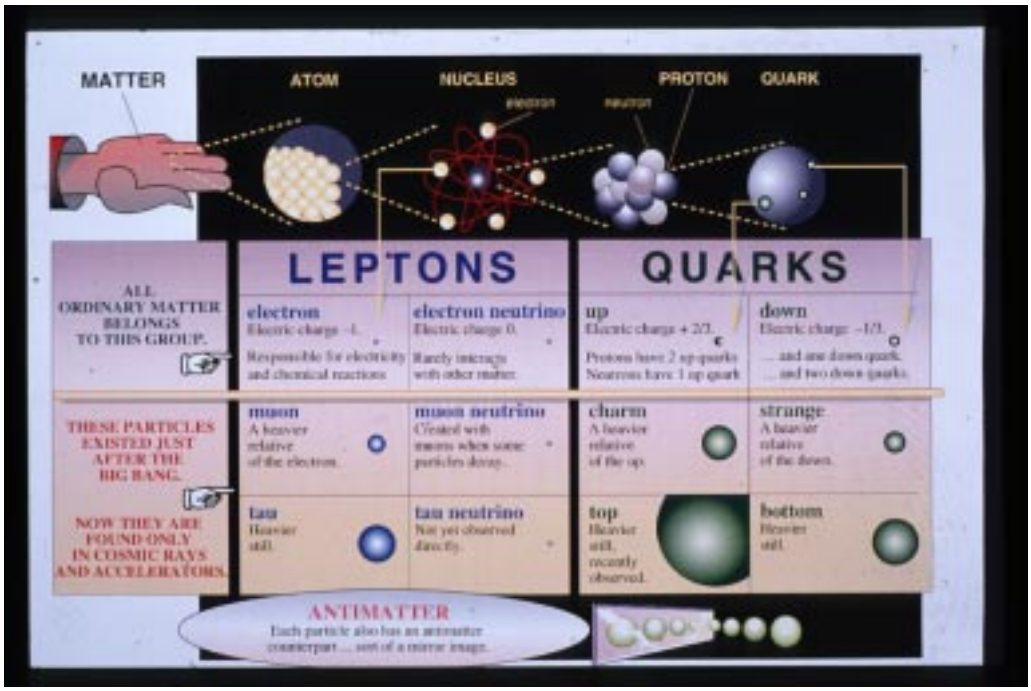
The Rationale for Particle Research

Particle physics seeks to learn the how and why of Nature's structure; such fundamental questions are expressions of mankind's innate curiosity about the world. The last twenty-five years of research have revealed a strikingly simple basis for all the physical phenomena we encounter: all matter is explained by a dozen elementary particles and a few forces.

The search for fundamental particles makes extreme demands on experimental techniques. In meeting these challenges, new instruments and technologies are created with enormous potential for other sciences and for practical applications. Accelerators designed for research became instruments for medical diagnosis and treatment. The instruments that detect particles have been adapted to permit visualization of human organs. The need for rapid communication among experimental particle physics teams led to the invention of the World Wide Web.

Particle physics plays an important part in advanced scientific and technical education. The excitement of the field attracts many talented young scientists and engineers. Most go on to find careers in industry, where their experience of working on new problems in a state-of-the-art high-tech environment is highly valued.

The Hierarchy of Particles



courtesy CERN

We now know that there are just six basic quarks. The two lightest quarks are responsible for the neutron and protons at the heart of the atomic nucleus. The heaviest

two quarks, the b and t, were discovered only recently. Why are there six quarks, when we need just two to build the everyday world? Why is the top quark so massive – over a hundred thousand times heavier than the lightest quarks? Does the top quark hold hints for understanding why matter has mass? So far there are no answers to these questions, but clues may come from experiments planned for existing and new facilities in the U.S. and around the world, where the heavy quarks will be made in profusion.

There are also six known leptons – particles like the electron discovered 100 years ago this spring and its companion, the electron neutrino, which enables radioactive decays. The electron is a vital component of atoms, and has triggered the twentieth century revolutions of electronics and computing. The reasons for the heavier leptons, the muon and tau and their neutrinos are more mysterious.

Questions for the Future

Although our current theory of elementary particles and forces is remarkably successful in explaining both the ordinary phenomena of atoms and molecules and the collisions of high-energy particles produced in accelerators, this theory challenges us to address new, fundamental questions. For example, the historic hope for unification of all the forces suggests that entire new classes of fundamental particles could be required.

Today's theory of fundamental forces indicates the basic physical constants, indeed the whole basic nature of the universe, is really just one of many alternatives that nature might have chosen. How was this "choice" made? The answer may come only when we discover a new class of particles at an existing accelerator, or perhaps at the one being constructed in Geneva, Switzerland, with the U.S. joining nations in Europe and around the globe.

The discoveries being made in particle physics help us to understand not just the world around us, but the origins and nature of the universe. During the Big Bang, which began the universe, all the elementary particles were present, not just the ones that make up the tangible matter around us. Though matter and anti-matter were probably present in equal amounts, now only matter remains. This puzzle motivates much of today's research. There is persuasive evidence that more than 90% of the matter in the universe is unacccounted for. It may be in the form of neutrinos, or it may be in the form of some yet-to-be-discovered particles, for example those required in theories which unify all the forces.

By trying to answer questions that intrigue all of us – what is the world made of? are there forces of nature yet to be discovered ? – particle physics pushes us to find more and more effective ways of making measurements, faster ways of recording and analyzing data, and better ways of sharing and distributing information. The result is not just a better understanding of our physical surroundings but better technologies and instruments for our lives. The quest for a fundamental understanding of nature is a challenge worthy of our country's support. It will inspire young people to seek education and training that will prepare them to make innovative contributions in science and throughout the emerging technological fields.